ULTRASHORT PULSES IN MULTICOMPONENT MEDIA AND PHOTONIC BANDGAP STRUCTURES

2nd Interim Report
by

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During the reporting period we have developed the mathematical algorithms and programs for the study of the femtosecond pulse propagation in an extended medium of the two-level atoms. The regime of the inversionless superradiance in the two-component superradiative medium has been investigated. It has been described the spatio-temporal nonlinear dynamics of coherent field in periodic resonant structures with arbitrary modulation of atomic density and gain gratings</td></tr>
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ULTRASHORT PULSES IN MULTICOMPONENT MEDIA AND PHOTONIC BANDGAP STRUCTURES

(1) The main goals of proposed research are:

Study of the specific features of ultrashort pulse propagation and dynamic nonlinear Bragg diffraction in two- and three-dimensional photonic bandgap structures;

Develop methods for the control of pulse duration and shape; and

Investigate coherent methods of ultrashort pulse formation, based on coherent interactions in multi-component media and photonic bandgap structures.

In accordance with the above mentioned goals during reporting period we have developed the mathematical algorithms for the study of the dynamics of the femtosecond pulse propagation in the medium of the two-level atoms. The conditions for the generation of harmonics of the incident pulse frequency are determined. The results of preliminary computer simulations enable us to estimate the required parameters for the quasi-continuum emission by the atomic gases.

The study of the dynamics of the two-component superradiance has shown that the generation can occur even in the case when the concentration of resonantly absorbing atoms exceeds the concentration of the resonantly amplifying ones. In this case the net population inversion is negative during the whole process of emission. Nevertheless the superradiance pulses with a sufficiently high power and sufficiently short duration can be produced in comparison with the mono-component superradiative media.

It has been predicted earlier that the gap soliton of self-induced transparency propagates at the Bragg frequency in discrete resonant structure, which consist of a set of ultrathin layers of two-level atoms. We consider theoretically the short pulse transmission in a resonant one-dimensional Bragg structure with arbitrary periodic modulation of atomic density. This model could be realized, for instance, in experiments with colloidal crystals. It has been found the analytical and numerical solutions of Maxwell-Bloch equations, which describe the spatio-temporal dynamics of gap solitary wave formation and propagation in the case when the frequency is in the linear forbidden gap band of arbitrary resonant periodic Bragg structure. The velocity and form of the pulse depends on the profile of atomic density modulation. The pulse propagation in sinusoidal structure is similar to the case of discrete Bragg structure.

We studied also the coherent decay of optically-written sinusoidal gain grating under Bragg condition. Describing this process by numerical solution of coupled-mode Maxwell-Bloch equations we investigated the dependence of the spatio-temporal dynamics of field and inverse population of atoms on frequency shift and initial inverse population. The coherent interaction of incident pulse with the gain grating leads to its amplification and shortening.

List of publications:

(*a*) published:

1. Andreev A.V, Polevoy P.V. «Specific features of superradiance in two-component media», Laser Physics, v.8, no.2, 1-4 (1998)

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2. Andreev A.V, Polevoy P.V. «Pulse pair propagation in two-component media». Abstract for CLEO/Europe-EQEC'98 Conference.

3. Mantsyzov B.I. «Nonlinear Bragg diffraction and solitary waves in multidimensional resonant periodical strucrures». ». Abstract for CLEO/Europe-EQEC'98 Conference.

4. Mantsyzov B.I., Kneubuehl F.K. «Spatio-temporal nonlinear dynamics of coherent field in periodic resonant structure and gain grating». ». Abstract for CLEO/Europe-EQEC'98 Conference.

5. Mantsyzov B.I.«Nonlinear solitary waves in 2D and 3D resonant periodic structures». Abstract for CLEO/IQEC'98 Conference.

(2) Brief statement of research plans for remainder of the contract period:

1. The investigation of the specific features of pulse amplification in the multi-component media and gain grating to define the optimal conditions for coherent pulse compression and amplification;

2. study of the characteristic properties of the coherent interactions in the three-level atomic media for the development of the methods of pulse parameter control;

3. exploration of the possibility for self-similar pulse formation during the process of the nonlinear diffraction in the excited photonic bandgap structures and gain grating;

4. the development of the mathematical algorithms and computations for the Maxwell-Bloch equations in the general case of ultrashort pulses to describe a pulse dynamics beyond the slowly varying envelope approximation.

(3) The Check of United States Treasury for line item 0001 was received at the middle of January and it is now in the process of conversion.

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Specific Features of Superradiance in Two-Component Media

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Abstract—Specific features of superradiance in two-component media are discussed. It is demonstrated that the introduction of a resonantly absorbing component into a superradiant medium considerably broadens the possibilities to control the parameters of superradiance pulses.

1. INTRODUCTION

Superradiance is a collective coherent spontaneous decay of a system of excited atoms or molecules. This phenomenon was predicted by Dicke [1] in 1954. It was demonstrated that the growth in the number density of excited particles increases the rate of radiative spontaneous decay, and incoherent decay, when radiation intensity is proportional to the number of excited particles N ($I_{SP} \sim N$), is replaced by coherent spontaneous decay—superradiance. The intensity of superradiance is proportional to the number of excited particles squared ($I_{SR} \sim N^2$). Consequently, in a macroscopic system, when $N \gg 1$, coherent radiation is much stronger than incoherent radiation. In the first experiment [2, 3], the superradiance intensity was higher than the intensity of ordinary spontaneous emission by a factor of more than 10^{10}.

Investigation of superradiance in gas media [4–7] and metal vapors [8–10] can be considered as the first stage of the experimental development of the theory of superradiance. In first experiments, the density of excited atoms or molecules fell within the range $n = 10^{10}$–10^{12} cm^{-3}. Subsequently, the density of excited particles was increased by two to three orders of magnitude. At the next stage, superradiance from solids, where $n_0 \approx 10^{16}$ cm^{-3}, has been studied [11, 12].

Initially, superradiance was considered as a method of cavity-free lasing, since there were no mirrors on the boundaries of active superradiant media, and even cell ends were cut at a Brewster angle. However, currently, the theory of superradiance in an optical cavity [13, 14], the theory of mode superradiance [15], and the theory of superradiance in two-component media [16–20] are being developed. Two-component media are of undeniable interest for the generation of high-power short coherent pulses [16–18, 20]. Superradiance pulses from two-component media are characterized by considerable delay times, appreciably exceeding the durations of superradiance pulses, which may allow us to substantially loosen requirements to the duration of the pumping pulse [17]. The feasibility of the experimental implementation of two-component superradiance and the problems associated with the choice of resonant media are discussed in [20]. The specific features that distinguish two-component media from one-component media stem from a more complex dynamics of pulse generation and amplification [16, 21] in two-component media. Therefore, two-component media may permit one to implement regimes, e.g., subthreshold pulse amplification [22] or superradiance without inversion, considered in this paper, that cannot arise in one-component media. Therefore, the investigation of the properties of two-component media and the application of such media provide an opportunity to propose new methods of lasing and compression of short coherent pulses.

2. FORMULATION OF THE PROBLEM

Let us investigate the dynamics of superradiance in a medium that consists of atoms of two sorts, a and b, with different magnitudes of the transition dipole moment, $d_a < d_b$. Since the Rabi frequency is proportional to the magnitude of the transition dipole moment, $\Omega \sim d$, we have $\Omega_a < \Omega_b$. Atoms with a higher Rabi frequency (atoms of the b sort) will be referred to as fast atoms, whereas atoms of the a sort will be referred to as slow atoms. We also assume that atoms in the two-component medium satisfy the resonance conditions (Fig. 1), i.e., the relation

$$\omega_b = \omega_a + \Delta, \quad |\Delta| \ll \omega_a, \omega_b, \tag{1}$$

is met for the relevant transition frequencies.

We consider a two-component medium where fast atoms initially reside in the ground state and slow atoms are excited by a pumping pulse with a finite duration.

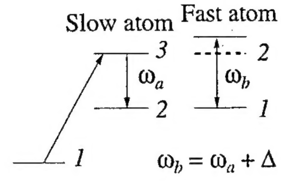

Fig. 1. Energy diagram of the levels of slow and fast atoms in a two-component medium.

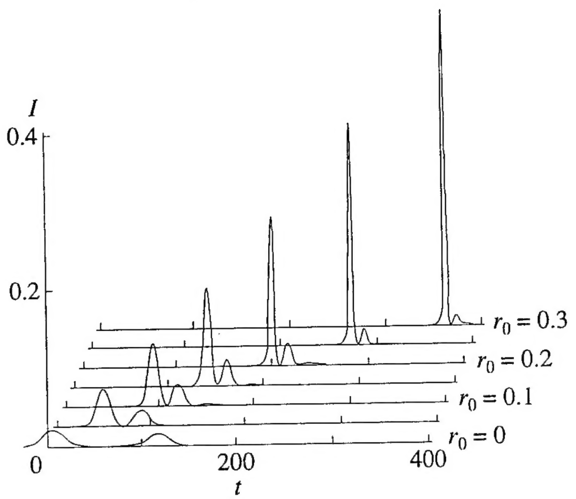

Fig. 2. Intensity profiles of superradiance pulses in a two-component medium for different concentrations of fast atoms.

The generation process in such a medium is governed by a set of Maxwell–Bloch equations for slowly varying amplitudes ($a_{1,2}$) of counterpropagating waves, polarizations of fast ($p_{1,2}$) and slow ($P_{1,2}$) atoms, and population differences between the levels 2 and 1 (r) for fast atoms and levels 3 and 2 (R) for slow atoms [16]:

$$\frac{\partial a_1}{\partial t} + \frac{\partial a_1}{\partial x} = P_1 + p_1 + Q_0\frac{1+R}{2} + q_0\frac{-r_0+r}{2},$$

$$\frac{\partial a_2}{\partial t} - \frac{\partial a_2}{\partial x} = P_2 + p_2 + Q_0\frac{1+R}{2} + q_0\frac{-r_0+r}{2},$$

$$\frac{\partial P_1}{\partial t} + \alpha_a P_1 = \beta_a a_1 R,$$

$$\frac{\partial P_2}{\partial t} + \alpha_a P_2 = \beta_a a_2 R,$$

$$\frac{\partial p_1}{\partial t} + (\alpha_b + i\Delta)p_1 = \beta_b a_1 r, \tag{2}$$

$$\frac{\partial p_2}{\partial t} + (\alpha_b + i\Delta)p_2 = \beta_b a_2 r,$$

$$\frac{\partial R}{\partial t} = -(a_1 P_1 + a_2 P_2) + \frac{1}{\sqrt{\pi}}\frac{1}{\tau_{pump}}\exp\left\{-\frac{(t-t_0)^2}{\tau_{pump}^2}\right\},$$

$$\frac{\partial r}{\partial t} = -(a_1 p_1 + a_2 p_2).$$

The field amplitude $a(x, t)$ in the set of equations (2) is normalized in such a manner that $n(x, t) = |a(x, t)|^2$ is the quantum number density expressed in units of the density of slow atoms, $n_a = N_a/V$. The population of slow atoms varies within the range $-1 \le R \le 1$, whereas the population of fast atoms varies within the range $-r_0 \le r \le r_0$. In other words, the amplitude of population variation for fast atoms is determined by the ratio of component concentrations: $r_0 = N_b/N_a$.

The model described above ensures a good agreement between the results of numerical simulation [17] and the data of real physical experiments [23] in the case of a one-component medium.

3. THE MAIN RESULTS

Numerical simulation shows that the spatiotemporal dynamics of superradiance in a two-component medium qualitatively differs from the dynamics of superradiance in a one-component medium [16, 17]. In a one-component medium, generation starts at the boundary of the active medium. Then, generation evolves propagating toward the inside of the medium. In a two-component medium, generation arises inside the medium, which increases the efficiency of the release of the energy stored in the medium.

These effects are illustrated by Fig. 2, which displays the intensity profiles of superradiance pulses in a two-component medium plotted for different concentrations r_0 of fast atoms. The first generation pulse arises in a medium where $r_0 = 0$. In other words, this pulse is equivalent to superradiance in a one-component medium. As can be seen from Fig. 2, adding fast resonant atoms that initially reside in the ground state to a superradiant medium, one can considerably increase the peak intensity of superradiance pulses and simultaneously reduce their duration. Thus, Fig. 2 clearly demonstrates that the intensity of two-component superradiance may be substantially higher than the intensity of one-component superradiance.

Evidently, the growth in the density of fast atoms increases absorption in the medium and, therefore, cannot give rise to a permanent growth in the intensity of superradiance pulses. When the concentration of fast atoms becomes higher than a certain threshold [16, 17], generation in a two-component medium becomes impossible. Thus, two-component superradiance has a threshold character. However, the threshold concentration of fast atoms r_{th} may vary, depending on the parameters of a two-component medium. In particular, the value of r_{th} can be made large [18, 19]. In such a situation, the regime of superradiance without inversion becomes possible.

Figure 3 displays the intensity (Fig. 3a) and duration (Fig. 3b) of superradiance pulses in a two-component medium as functions of the concentration of fast atoms. Recall that the normalization was introduced in such a manner that the concentration of fast atoms is expressed in units of the number of slow atoms. Conse-

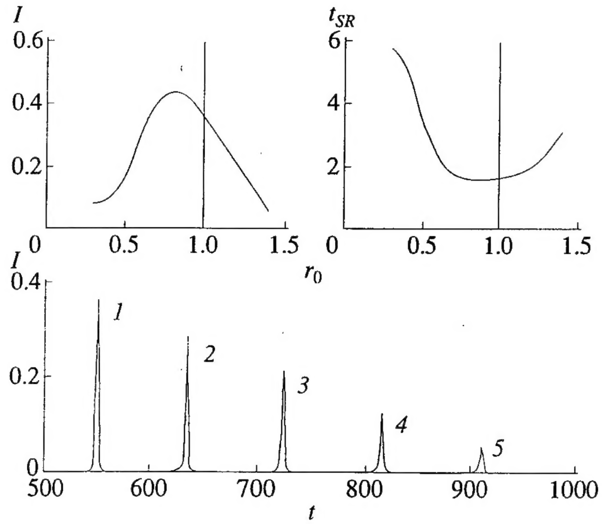

Fig. 3. (a) Intensity and (b) duration of superradiance pulses in a two-component medium as functions of the concentration of fast atoms. (c) Intensity profiles of superradiance pulses for different concentrations of fast atoms: (*1*) r_0 = 1.0, (*2*) 1.1, (*3*) 1.2, (*4*) 1.3, and (*5*) 1.4.

quently, the equality $r_0 = 1$ implies that the concentrations of slow and fast atoms are equal to each other in a two-component medium. Vertical dashed lines in Fig. 3 indicate the value $r_0 = 1$. At this point, the concentration of slow atoms is equal to the concentration of fast atoms, and the total population difference $(R_0 - r_0)$ is equal to zero. As can be seen from Fig. 3, generation can arise in a two-component medium even when the number of resonant atoms in the ground state is greater than the number of excited resonant atoms. Note that, in the range $r_0 > 1$, where the concentration of atoms in the ground state is greater than the concentration of excited atoms, and the total population difference in a two-component medium is negative, $(R_0 - r_0) < 0$, superradiance pulses with a sufficiently high power and sufficiently short duration can be produced within the entire generation process.

The regime considered above can be referred to as superradiance without inversion. Figure 3c displays the intensity profiles of superradiance pulses for various concentrations r_0 of fast atoms. As can be seen from Fig. 3c, the pulses of two-component superradiance are characterized by considerable delay times, which appreciably exceed the duration of these pulses. Although the intensity of superradiance pulses lowers with the increase in the concentration of the fast component in the range $r_0 > 1$, the intensity of such pulses is comparable with the maximum intensity, which is achieved in the case under study when $r_0 \approx 0.75$.

Note that the situation considered above is not optimal. Varying parameters of two-component media, one can further increase the peak intensity of the generated pulses and reduce their duration [18, 19].

The insertion of a two-component inhomogeneously broadened superradiant medium into an optical cavity [24] opens up broad opportunities in controlling parameters of superradiance pulses. In the case of cavity-free superradiance, two pulses propagating along the active medium in opposite directions are produced. We can accumulate the energy of two pulses of cavity-free superradiance in a single superradiance pulse by implementing a cavity with a totally reflecting mirror. In such a situation, due to the coherence of interaction, the peak intensity will be increased at least by a factor of four, and the duration of the cavity superradiance pulse will be reduced. Varying the configuration of the optical cavity, parameters of inhomogeneously broadened two-component media [24], and the distribution of the fast component, one can increase the intensity of the generated pulses. Thus, two-component media provide an opportunity to produce superradiance pulses with much higher power and much shorter duration than in the case of conventional one-component media. Therefore, the investigation of the properties of two-component media opens up new opportunities in controlling the parameters and the waveform of the generated pulses.

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REFERENCES

1. Dicke, R., 1954, *Phys. Rev.*, **93**, 99.
2. Skribanowitz, N., Herman, I.P., MacGillvray, J.C., and Feld, M.S., 1973, *Phys. Rev. Lett.*, **30**, 309.
3. Herman, I.P., MacGillvray, J.C., Skribanowitz, N., and Feld, M.S., 1974, in *Laser Spectroscopy* (New York: Plenum).
4. Ehrlich, J.J., Bowden, C.M., Howgate, D.W., *et al.*, 1978, in *Coherence and Quantum Optics* (New York: Plenum).
5. Rosenberger, A.T., DeTemple, T.A., Bowden, C.M., and Sung, C.C., 1978, *J. Opt. Soc. Am.*, **68**, 700.
6. Scherrer, D.P. and Kneubuhl, F.K., 1993, *Infrared Phys.*, **34**, 227.
7. Scherrer, D.P., Kalin, A.W., Kesselring, R., and Kneubuhl, F.K., 1992, *Opt. Commun.*, **87**, 249.
8. Gross, M., Fabre, C., Pillet, P., and Haroche, S., 1976, *Phys. Rev. Lett.*, **36**, 1035.
9. Flusberg, A., Mossberg, T., and Hartmann, S.R., 1977, in *Cooperative Effects in Matter and Radiation* (New York: Plenum).
10. Vrehen, Q.H.F., 1979, in *Laser Spectroscopy* (Berlin: Springer).

11. Florian, R., Schwan, L.O., and Schmid, D., 1984, *Phys. Rev. A*, **29**, 2709.
12. Schmid, D., Schwan, L.O., and Schiller, A., 1989, *Cryst. Latt. Def. Amorph. Mater.*, **18**, 27.
13. Andreev, A.V., Tikhomirov, O.Yu., and Fedotov, M.V., 1988, *Zh. Eksp. Teor. Fiz.*, **94**, 40.
14. Andreev, A.V., 1993, *Kvantovaya Elektron.*, **20**, 581.
15. Golubyatnikova, E.R., Kocharovskii, V.V., and Kocharovskii, Vl.V., 1994, *Kvantovaya Elektron.*, **21**, 849.
16. Andreev, A.V. and Polevoy, P.V., 1994, *Quantum Opt.*, **6**, 57.
17. Andreev, A.V. and Polevoy, P.V., 1993, *Kvantovaya Elektron.*, **20**, 991.
18. Andreev, A.V. and Polevoy, P.V., 1995, *Infrared Phys. Technol.*, **36**, 15.
19. Andreev, A.V. and Polevoy, P.V., 1996, *Kvantovaya Elektron.*, **23**, 647.
20. Andreev, A.V., Derzhavin, S.I., Mashkovsky, D.A., and Polevoy, P.V., 1996, *J. Russ. Laser Res.*, **17**, 409.
21. Andreev, A.V. and Polevoy, P.V., 1994, *Zh. Eksp. Teor. Fiz.*, **106**, 1343.
22. Andreev, A.V. and Polevoy, P.V., 1996, *J. Russ. Laser Res.*, **17**, 501.
23. Malcuit, M.S., Maki, J.J., Simkin, D.J., and Boyd, R.W., 1987, *Phys. Rev. Lett.*, **59**, 1189.
24. Andreev, A.V. and Kobelev, D.Yu., 1996, *Laser Phys.*, **6**, 774.

SPELL:

PULSE PAIR PROPAGATION IN TWO-COMPONENT MEDIA

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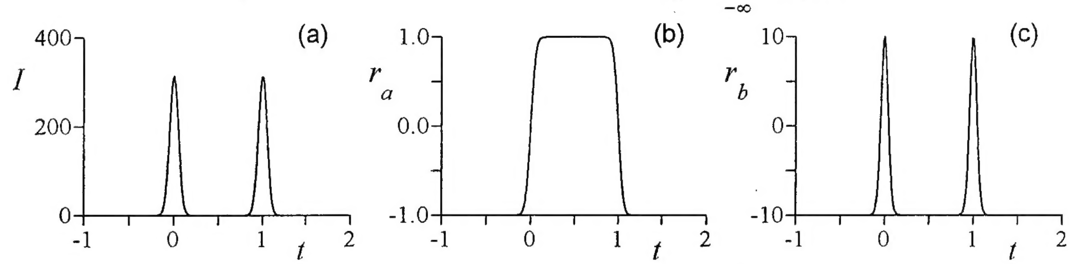
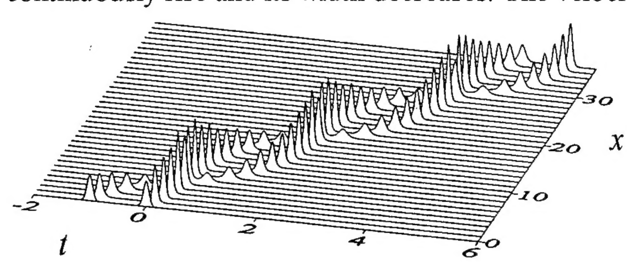
We report here the results of computer simulations on the coherent pulse propagation in the two-component medium. Two-component medium consists of two species of the resonant atoms which differ in the value of the dipole moments of the resonant transitions ($d_b > d_a$). It is well known that the Raby frequency is proportional to the dipole matrix element of transition ($\Omega \sim d$). Hence $\Omega_a < \Omega_b$ and we shall call the "a" atoms as slow, and the "b" atoms as fast.

The theory shows that the dynamics of pulse propagation in the two-component media depends primarily on the value of the parameter $\gamma = (| d_a |^2 r_a)/(| d_b |^2 r_b)$, where r_a (r_b) is the concentration of the slow (fast) atoms. We consider the subthreshold regime: $\gamma < 1$. It is well known that the ultrashort pulse evolution in the resonant media depends significantly on the area of the incident pulse θ. In the two-component medium the incident pulse has the different area with respect to the slow and fast atoms $\theta_{a,b} = \int_{-\infty}^{\infty} \Omega_{a,b}(t)\, dt$



We study the dynamics of propagation of two pulses (Fig.1a) in the two-component medium. It is assumed that the fast and slow atoms are initially in the ground state and that area of each incident pulse with respect to the slow atoms is equal to π ($\theta_a = \pi$). In the case $d_b = 2d_a$ the pulse area with respect to the fast atoms is twice larger: $\theta_b = 2\pi$ (Fig.1bc). The first pulse in pair propagates in the absorbing medium, it loses its energy by exciting the slow atoms of the two-component medium. The pulse is broadened and decreases in intensity. The second pulse transfers the excited slow atoms into the ground state. The pulse intensity continuously rise and its width decreases. The velocity of the second pulse which propagates in the amplifying medium is higher than velocity of the first one and after some time the pulses are changed in their places. Therefore this two pulses combine into the pair in two-component medium and begin to propagate as an unified excitation. The Fig.2 shows the spatio-temporal dynamics of bound pulses in the two-component medium. We can see that the bound pulses are changed their places in the process of propagation and the dynamics of the system repeats itself periodically. We can see that the bound pulses overtake each other and their amplitudes and temporal widths oscillate near some average values.



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Nonlinear solitary waves in 2D and 3D resonant periodic structures

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The study of the nonlinear interactions in periodic structures has gain considerable interest in the past few years[1]. This is due to the finding of the novel kind of nonlinear solitary waves which are propagated at Bragg frequency within the linear forbidden gap band of the periodic medium. It has been shown that gap solitons and oscillating solitary waves exist in one-dimensional structures with resonant[2] and Kerr[3] nonlinearity. These waves are formed by two counterpropagating coupled Bragg modes. Here we investigate theoretically the dynamics of formation and propagation of nonlinear solitary waves in the general case of two-wave diffraction problem in 2D and 3D periodic resonant structures. The vector Bragg condition $\boldsymbol{k_h} = \boldsymbol{k_0} + \boldsymbol{H}$ for the wave vectors $\boldsymbol{k_0}$ and $\boldsymbol{k_h}$ of the incident and diffracted waves and the reciprocal lattice vector $\boldsymbol{H}$ is to be setisfied in this problem.

The equations of two-wave nonlinear dynamic diffraction have been derived from the semiclassical Maxwell-Bloch equations describing the coherent light-matter interaction under Bragg condition. By means of analytical and numerical integration of the equations we investigated the process of formation and propagation of Bragg solitary waves for the different geometric schemes of diffraction. It has been shown that nonlinear solitary waves appear both in the case of Bragg geometry of diffraction like gap two-wave solitons and in the case of Laue geometry of diffraction like two-wave solitons of nonlinear Borrmann effect. The "Laue soliton" propagates in the direction of the normal to reciprocal lattice vector. The numerical simulation of diffraction process has given the possibility to study the wave dynamics in a finite medium under different boundary conditions.

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1. "Development and Applications of Photonic Band Gap Materials", ed. by C.M.Bowden, J.P.Dowling, and H.O.Everitt, special issue of J.Opt.Soc.Am. B, v.10, 279 (1993).
2. B. I. Mantsyzov, Phys.Rev. A, v.51, 4939 (1995).
3. C. M. de Sterke and J. E. Sipe, "Gap Solitons", in Progress in Optics, ed. by E.Wolf, v. XXXIII (1994).

Spatio-temporal nonlinear dynamics of coherent field in periodic resonant structures and gain gratings

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Interest in nonlinear light-matter interaction in distributed feedback structure has considerably grown in the last years [1]. The nonlinear spatio-temporal dynamics of the field in the structures is qualitatively different from that both for the case of linear Bragg diffraction and the nonlinear interaction outside the diffraction condition. It has been predicted earlier[2] that gap soliton of self-induced transparency propagates at the Bragg frequency in discrete resonant structure, which consist of a set of ultrathin layers of two-level atoms.

Here we consider theoretically the short pulse transmission in a resonant one-dimensional Bragg structure with arbitrary periodic modulation of atomic density. This model could be realized, for instance, in experiments with colloidal crystals[3]. We present analytical and numerical solutions of Maxwell-Bloch equations, which describe the spatio-temporal dynamics of formation and propagation of gap solitary waves within the linear forbidden frequency gap band of arbitrary resonant periodical Bragg structure. The velocity and the form of the pulse depends on the profile of atomic density modulation. The pulse propagation in sinusoidal structure is similar to the case of discrete structure.

We studied also the coherent decay of optically-written sinusoidal gain grating under Bragg condition. Describing this process by numerical solution of coupled-mode Maxwell-Bloch equations we investigated the dependence of the spatio-temporal dynamics of field and inverse population of atoms on frequency shift and initial inverse population. The coherent interaction of incident pulse with the gain grating leads to its amplification and shortening.

1. F. K. Kneubuehl, *Theories on Distributed-feedback Lasers. Laser Science and Technology* (Ed. by V. S. Letokhov, C. V. Shank, Y. R. Shen and H. Walther), Vol.14, Harwood Academic, Switzerland (1993); J. Feng, F.K. Kneubühl, *Solitons and Chaos in Periodic Nonlinear Optical Media and Lasers*, Chapter 15 in "Advanced Electromagnetism: Foundations, Theory, Applications", World Scientific Publ. Co., Singapore, (1995).
2. B. I. Mantsyzov, Phys.Rev. A 51, 4939 (1995).
3. W. L. Vos, R. Sprik, A. van Blaaderen, A. Imhof, A. Lagendijk, and G. H.Wegdam, Phys.Rev. B 53, 16231 (1996).